AD-E000004

(12)

NRL Memorandum Report 3549

(6) # High Energy Ions from a Nd-Laser Produced Plasma

(10) R. DECOSTE
University of Maryland
College Park, Maryland

and

B. H. RIPIN
Laser Plasma Branch
Plasma Physics Division

(9) Interim report,

(11) July 1977 (12) 12 p.

(14) NRL-MR-3549

(18) SEIE

(19) AD-E000 117

NAVAL RESEARCH LABORATORY
Washington, D.C.

251 950

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 3549	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HIGH ENERGY IONS FROM A Nd-LASER PRODUCED PLASMA		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing NRL problem. 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. Decoste* and B.H. Ripin		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem H02-29A
11. CONTROLLING OFFICE NAME AND ADDRESS Energy Research and Development Administration Washington, D.C. 20545		12. REPORT DATE July 1977 13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Work performed at the Naval Research Laboratory under the auspices of the Energy Research and Development Administration.

*University of Maryland, College Park, Maryland

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

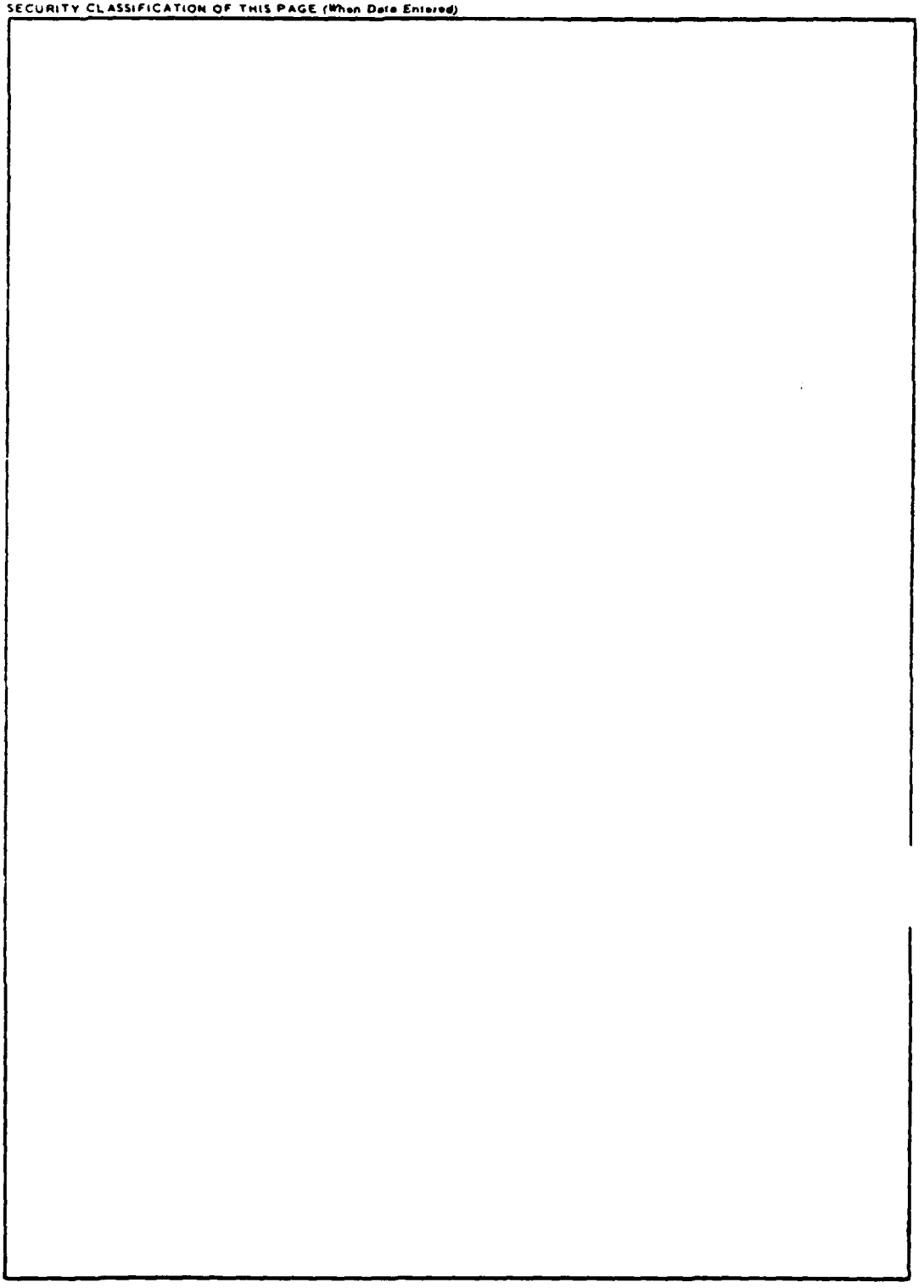
Ions
Laser-plasma
Plasma expansion
Laser fusion
Ion analyzer

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Measurements of the asymptotic energy distribution of the different high energy ion species at Nd-laser irradiance 10^{15}-10^{16} W/cm^2 on a CH_2 planar target are presented and the acceleration mechanism of these high energy ions is discussed. Multipeak structure between 10 and 100 keV is observed on the H^+ ion distribution. A disproportionate number of H^+ ions with E/Z higher than the C^{+Z} ions is also observed.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)



HIGH ENERGY IONS FROM A Nd:LASER PRODUCED PLASMA

It is now generally recognized that the energy distribution of ions observed far from a solid target at high laser irradiance can usually be divided into two distinct ion groups[1]: a low energy ion group,[1-3] containing most of the ablated target mass, and a small, but significant group, of higher energy ions. Electrostatic acceleration from a large localized pressure gradient set up by the inhibition of heat transport is the principle mechanism suggested for acceleration of these high energy ions.[4-6] In the case of the CO_2 laser-plasma interaction, the ion expansion observed on a charge collector suggests the existence of an electrostatic potential ϕ at the target. This interpretation assumes that different ions species would peak at the same energy E divided by their charge Z after expansion[7] ($E/Z = \phi$). This signature was not obvious in our Nd-laser-plasma experiments and a high energy ion analyzer had to be used for definitive results. Here we report some measurements of the asymptotic energy distribution of the high energy ion species in the case of a Nd-laser plasma and discuss the acceleration mechanism of these ions.

The laser used for these experiments was one beam of the NRL Nd-glass laser system PHAROS II ($\lambda_o = 1.06$ μm) delivering single 95 psec (FWHM) pulses (> 10^6 contrast ratio) on target at irradiance between 10^{15} and 10^{16} W/cm^2 through an f/1.9 aspheric lens. The thick planar polyethylene (CH_2) target was oriented at 45° to the laser axis with the ion analyzer axis normal to the target. The electric vector of the laser field was s-polarized, i.e., perpendicular to the plane of incidence. Up to 5 charge collectors were also used at different angles to monitor the angular distribution of the ion expansion. A schematic of the high energy ion anzlyzer is shown in

Note: Manuscript submitted June 28, 1977.

Fig. 1. The analyzer is basically a time-of-flight and electrostatic energy analyzer.[8] Ions between 1 and 500 keV/Z can be detected with energy resolution within ± 5%.

Two typical shots are shown in Figs. 2 and 3 to illustrate some general features observed in at least 70% of the 30 shots. Figure 2 shows the energy distribution of the different ion species as a function of their energy divided by charge on a single shot (19 J on target). The detailed shape and multipeak structure of the H^+ data is inferred from a charge collector as explained below. In this case there is a peak at 62, 32, and possibly one around 12 keV. A hydrogen peak is also observed on the neutral particle channel (see Fig. 1) around 32 keV. The neutral signal is a few percent of the H^+ peak at 32 keV and is detected by secondary electron emission from the collector. Two or three H^+ peaks are usually observed between 10 and 100 keV on most other shots. The most energetic H^+ peak is also generally found at higher E/Z then most carbon peaks. The H^+ distribution extends up to at least 200 keV and no higher energy peak structure is observed (between 200 and 500 keV) above the noise level of the detection system (which is 10% of the H^+ peak at 82 keV).

Typical energy distributions of carbon ions obtained under conditions very similar (20.2 J on target) to Fig. 2 are shown in Fig. 3a as a function of E/Z and in Fig. 3b as a function of E. The different carbon species do not appear to peak at the same E/Z or for the that matter quite the same E. The relative amplitude of the carbon peaks remained grossly the same from shot to shot and ionization stages below 3 were not observed. Some shots suggest that additional peak structure may also exist on the carbon species at lower energy. An extended analyzer energy range and more data at lower energy are required for definitive results.

A charge collector trace obtained on the same shot as in Fig. 2 and at roughly the same angle (47° from the laser axis) is shown in Fig. 4. The summation of the C^{+z} ion partial currents has been performed using the analyzer data. The detailed shape of the H^+ ion

distribution is obtained by subtraction of the carbon currents from the charge collector trace (after normalizing for differing solid angles and distances between the charge collector and the analyzer). In this case the charge collector trace has been scaled up by 20% to get good absolute agreement with the analyzer H^+ data points. It can be seen from Fig. 4 that most of the early peak structure in the charge collector trace is due to H^+ ions not C^{+z} ions. One also expects that the ratio of protons to carbon ions should be around 2 for a polyethylene (CH_2) target. Instead, the ratio of the number of protons in the first H^+ peak to the number of carbons in the first carbon peak (Fig. 4) is about 10 in approximate agreement with numerical code results.[13] Because of uncertainties in the relative secondary electron coefficient ratio of carbon ions to H^+ ions ($\gamma_C/\gamma_H = 5$ was used above)[9], an error by a factor of 2 could occur for this estimate.

The peak of the ion charge angular distribution grossly follows the target normal for the bulk of the plasma expansion but the high energy ions tend to peak between the lens axis and the target normal.

The general features of the ion distributions discussed above were observed in at least 70% of the shots although the relative peak structure on H^+ and the total number of high energy ions tended to fluctuate considerably from shot to shot.

One model[4-6] to explain the large directed velocities of these high energy ions invokes a large electron pressure gradient due to strongly inhibited heat transport. Spontaneously generated magnetic fields,[5,10] ion acoustic[11] and electron turbulence could reduce the electron thermal conductivity and thereby create large localized pressure gradients. An electrostatic potential is then created due to ambipolar expansion of the hot electrons with the ions. Large directed velocities can be expected due to acceleration by this ambipolar potential[12] and an important fraction of the hot electron energy can be transferred to ion kinetic energy.[6]

These theoretical models deal with only one ion fluid and, therefore, cannot predict the temporal and spatial separation of the different ion species during the expansion. The different ions species are expected to peak at the same E/Z only if they are accelerated through the same electrostatic potential. The fact that slightly higher E/Z are observed for H^+ than C^{+z} ions and that a disproportionate number of H^+ is measured would suggest that this condition is not exactly satisfied. The H^+ ions, being lighter than the C^{+z} ions, would tend to leave the interaction region first if subjected to the same initial pressure gradient. After the initial expansion the local accelerating field could become different for H^+ and C^{+z} ions since they do not expand at the same velocity and would tend to separate spatially. Numerical calculations with a one-dimensional three-fluid code has in fact shown this feature.[13] Then, finite heat conductivity and cold electron diffusion towards the hotter region would affect the H^+ and C^{+z} ions differently if partial spatial separation occurs. The multipeak structure on the H^+ distribution could be due to temporal or spatial variation of the pressure gradient.

Although the relative ordering of the carbon peaks in Fig. 3 could also be explained as due to spatial separation during the acceleration phase, this effect is expected to be less important because of their small differences in A/Z. Also, for the initial temperature expected the plasma should be nearly fully stripped and consist mostly of H^+ and C^{+6} ions. Then Fig. 3 would suggest that atomic processes were important during the expansion. Recombination[2,3] and charge exchange[14] between energetic C^{+6} ions and colder ablated plasma in front of the target would also produce ions with lower ionization stages at roughly the same energies as the C^{+6} and H^+ ion peaks. It has also been suggested that the ion wave turbulence induced by this expanding multi-component plasma could couple the species during the expansion.[15]

In conclusion, the asymptotic high energy ion distribution presented above are consistent with the assumption of a large localized pressure gradient providing that the ion species are separating during

the acceleration phase and atomic processes are occurring during the expansion. Additional theoretical work including the expansion of multi-ion fluids is required for a more complete comparison. The data shown here indicates that the interpretation of charge collector signals without independent knowledge of the charge species should be avoided.

The authors are grateful for helpful discussion with E. A. McLean, F. C. Young, S. E. Bodner and H. R. Griem.

REFERENCES

1. E. A. McLean, R. Decoste, B. H. Ripin, J. A. Stamper, H. R. Griem, and S. E. Bodner, Bull. Amer. Phys. Soc. 21, 1084 (1976), Appl. Phys. Lett. 31, 9 (1977).
2. R. R. Goforth and P. Polyamichev, J. Appl. Phys. 47, 3918 (1976).
3. E. E. Lovetskii, A. N. Hammerling, and V. S. Fetisov, Sov. J. Plasma Physics 1, 422 (1975).
4. R. C. Malone, R. L. McCrory and R. L. Morse, Phys. Rev. Lett. 34, 721 (1974).
5. R. S. Craxton and M. G. Haines, Phys. Rev. Lett. 35, 1336 (1975).
6. E. J. Valeo and Ira B. Bernstein, Phys. Fluids 19, 1348 (1976).
7. A. W. Ehler, J. Appl. Phys. 46, 2464 (1975).
8. R. Decoste and B. H. Ripin, Rev. Sci. Instrum. 48, 97 (1977).
9. K. H. Krebs, Forstchr. Phys. 16, 419 (1968).
10. J. A. Stamper and B. H. Ripin, Phys. Rev. Lett. 34, 138 (1975).
11. W. M. Manheimer, Phys. Fluids, 20, 265 (1977).
12. [illegible] Crow, P. L. Auer and J. E. Allen, J. Plasma Phys. 14, [illegible]5).
13. [illegible]oste and B. H. Ripin, Proceedings of the IEEE Conf. on [illegible]lasma Science, May 23-26, 1977, pg. 59. Also to be published.
14. Electron capture cross sections for C^{+z} ions expanding through several neutral gas backgrouns can be found in: V.S. Nickolaev, I. S. Dmitriev, L. N. Fateeva and Ya. A. Teplova, Soviet Phys. JETP 13, 695 (1961).
15. D. W. Forslund, J. M. Kindel, K. Lee and E. L. Lindman, Bull. Amer. Phys. Soc. 20, 1377 (1975), to be published.

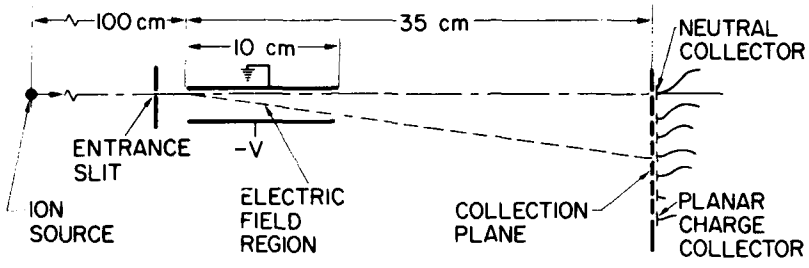


Fig. 1 — Schematic diagram of the high energy electrostatic ion analyzer

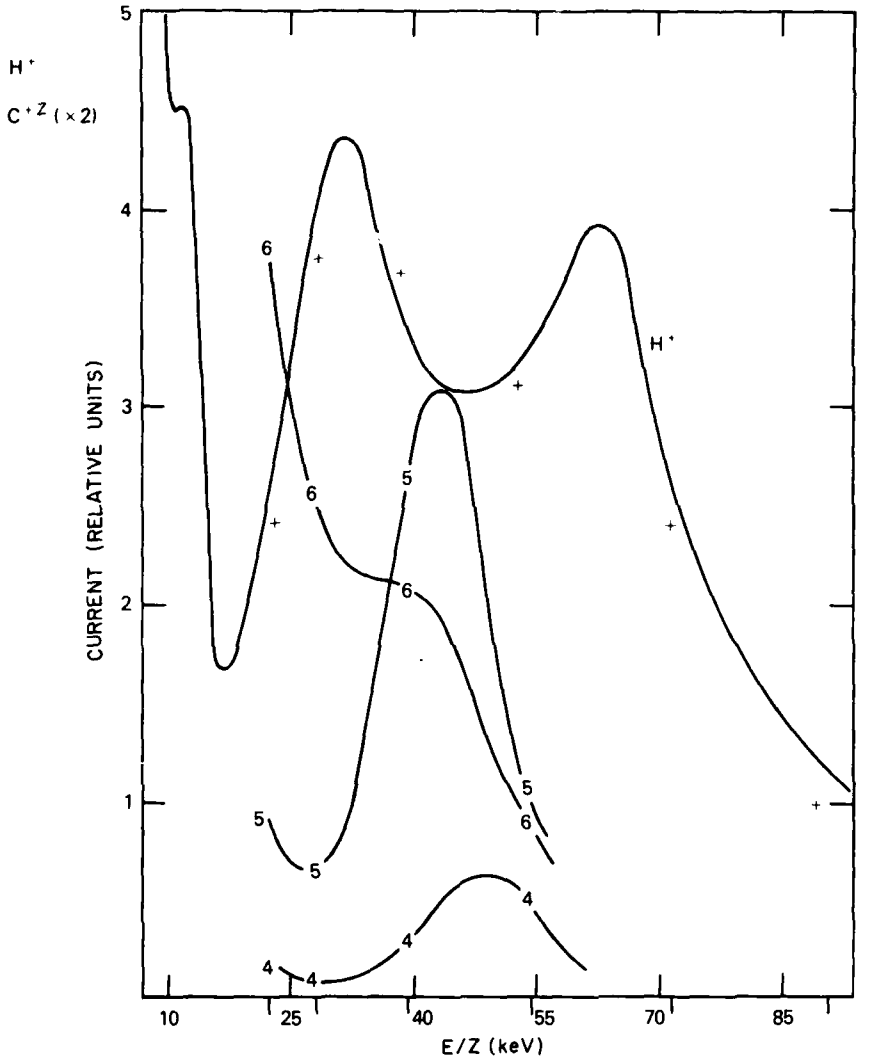


Fig. 2 — High energy ion distributions. The numbers represent the Z of C_{12}^{+z} ions and + the H^+ ions. The uncertainty is ±5% for the analyzer data points. The lines through the carbon species are smooth fits through the points and the detailed shape of the H^+ distribution is inferred from a charge collector.

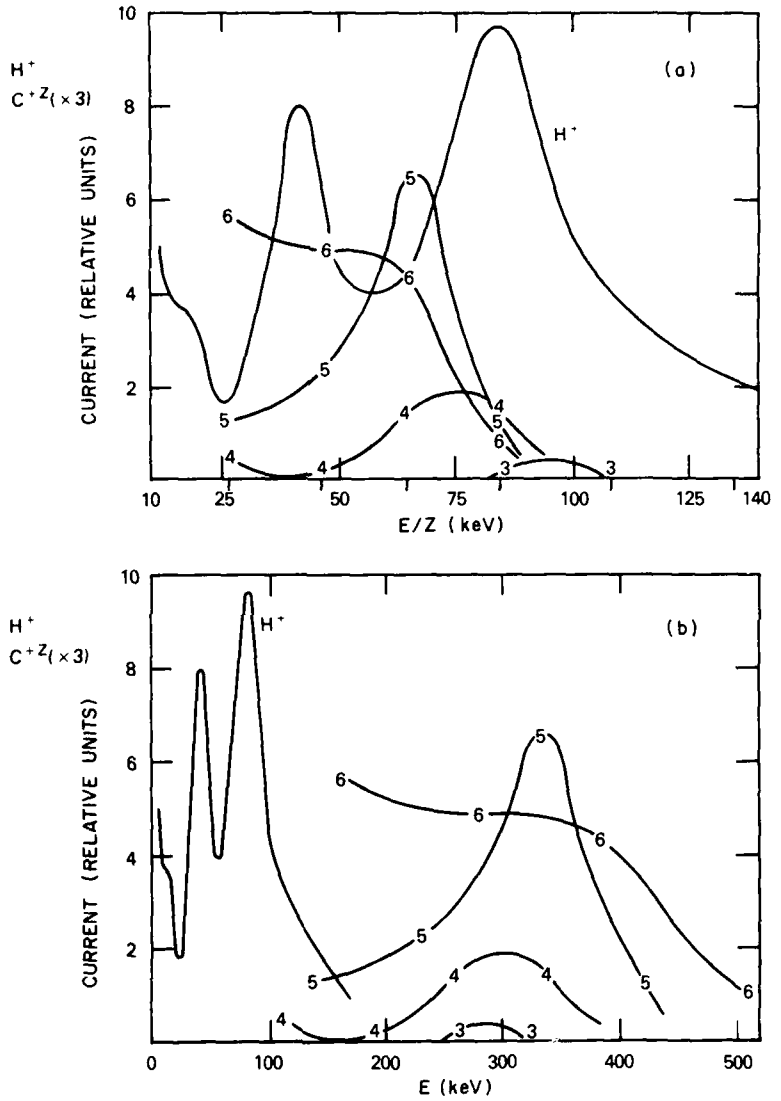


Fig. 3 — Carbon ion distributions as a function of E/Z and E. The H^+ ion distribution is shown as a reference.

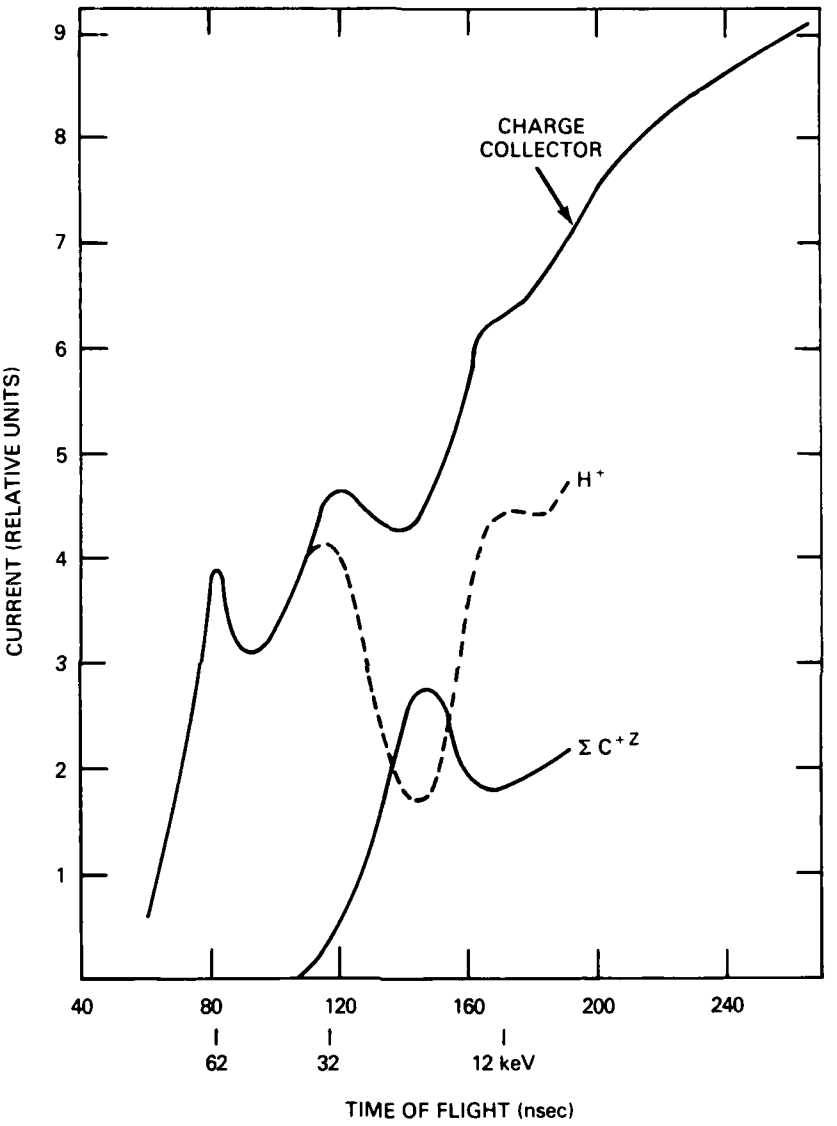


Fig. 4 — Partial current contributions of H^+ and carbon ions to the charge collector current recorded 26.7 cm from the target. The energy scale is for hydrogen.

DEPARTMENT OF THE NAVY

NAVAL RESEARCH LABORATORY
Washington, D.C. 20375

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DoD-316